SUITABILITY OF SHALLOW GROUNDWATER FOR IRRIGATION PURPOSE: THE CASE OF WONJI SHOA SUGAR ESTATE (ETHIOPIA)[†]

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ABSTRACT

This study evaluated the possibility of conjunctive use (CU) of shallow ground water (SGW) and surface water for irrigation use at Wonji Shoa Sugar Estate (WSSE)(Ethiopia). Irrigation suitability was investigated by taking 46 SGW samples from piezometers and hand-dug wells. Many physicochemical parameters (Mg^{2+}, Na^{+}, Ca^{2+}, K^{+}, CO_3^{-}, $SO4^{2-}$, HCO_3^{-}, Cl^{-}, TH, EC, TDS and pH) and other indices (MAR (magnesium adsorption ratio), SSP (soluble sodium percentage), SAR (sodium absorption ratio), RSC (residual sodium carbonate), KR (Kelly's ratio) and permeability index (PI)) were analyzed following standard procedures. The salinity and infiltration problems of SGW were found to be none to moderate with none chloride and boron ion toxicity. The sodium ion toxicity problems are slight to moderate. The SGW is generally categorized under C3S1 (high salinity and low sodium hazard). However, a high value of SSP and RSC indicate a high possibility of occurrence of infiltration problem when using the SGW. Hence, the CU of SGW and surface water must be practiced to minimize the potential problems of infiltration, salinization and their associated problems on soil and sugarcane productivity. Therefore, during CU planning, the optimum irrigation scheduling that considers the in situ use of groundwater table must be practiced.

KEY WORDS: infiltration; salinity; sodicity; sugarcane; toxicity; waterlogging.

RÉSUMÉ

[†] Adéquation des eaux souterraines peu profondes à des fins d'irrigation: le cas de Wonji Shoa Sugar Estate (Éthiopie)

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Cette étude a évalué la possibilité d'une utilisation conjointe (CU) de l'eau souterraine peu profonde (SGW) et de l'eau de surface à des fins d'irrigation au Wonji Shoa Sugar Estate (WSSE) (Éthiopie). L'aptitude à l'irrigation a été étudiée en prélevant 46 échantillons de SGW dans des piézomètres et des puits creusés à la main. De nombreux paramètres physicochimiques (Mg^{2+}, Na^{+}, Ca^{2+}, K^{+}, CO_3^{-}, $SO4^{2-}$, HCO_3^{-}, Cl^{-}, TH, EC, TDS et pH) et d'autres indices (MAR (taux d'adsorption de magnésium), SSP (pourcentage de sodium soluble), SAR (rapport d'absorption de sodium), RSC (carbonate de sodium résiduel), KR (rapport de Kelly) et indice de perméabilité (IP) ont été analysés conformément aux procédures standard. Les problèmes de salinité et d'infiltration de SGW se sont avérés nuls ou modérés et n'ont pas présenté de toxicité aux ions chlorure et bore. Les problèmes de toxicité des ions sodium sont légers à modérés. Le SGW est généralement classé dans la catégorie C3S1 (risque élevé de salinité et de faible teneur en sodium). Cependant, une valeur élevée de SSP et de RSC indique une forte possibilité d'apparition d'un problème d'infiltration lors de l'utilisation de SGW. Par conséquent, il faut pratiquer la CU de SGW et de l'eau de surface pour minimiser les problèmes potentiels d'infiltration et de salinisation ainsi que les problèmes qui leur sont associés sur la productivité du sol et de la canne à sucre. Par conséquent, lors de la planification de l'UC, il faut appliquer le programme d'irrigation optimal tenant compte de l'utilisation in situ de la nappe phréatique.

MOTS CLÉS: infiltration; salinité; sodicité; canne à sucre; toxicité; engorgement.

INTRODUCTION

Irrigation development within arid and semi-arid regions usually result in the development of the waterlogging and/or salinization. The strong climatic aridity is a pre-condition for salinization (Smedema, 1990; Arslan, 2012, Singh, 2017). Failure to invest on adequate and appropriate drainage facilities to manage shallow groundwater tables is a major cause for these problems among several factors (Smedema, 1990, Tyagi, 2014; Valipour, 2014; Wichelns and Qadir, 2015). Waterlogging and salinization of irrigated land are often referred to as twin problems, although they are really two quite different processes which are not always related or coinciding (Smedema, 1990). Irrigated land may become salinized without waterlogging when not enough water is applied for leaching while irrigation during the rainy season in semi-arid or humid climates may lead to waterlogging without salinization. These situations are the exceptions and as a rule waterlogging and salinization are indeed related and coinciding processes in irrigated land

(Smedema, 1990).

Water logging and salinization can cause negative impacts on agriculture, groundwater, agricultural infrastructures, human health and the environment. For instance, about 94% of the plantation fields of the Wonji-Shoa Sugar Estate (WSSE) (Ethiopia) are affected by critical waterlogging problem (Dinka et al., 2013; Dinka and Ndambuki, 2014). A study made by Dinka *et al*. (2013) indicated that WSSE has reached a stage where the groundwater table is under severe condition (< 1 m below ground) throughout the entire season and shows great spatial and seasonal variability. The potential causes, as suggested by Dinka and Ndambuki (2014) are the flat landscape, soil type (clayey), runoff, and rainfall, over irrigation and poor drainage.

The waterlogging problem at WSSE is negatively affecting the socio-economics and environment of the region and hence challenging the sustainability of WSSE. It has negative impacts on crop production and productivity, machinery performances, agronomic practices, yield-increasing interventions, soil behaviour and performance, etc (Dinka *et al*., 2014). The potential effects of shallow groundwater table (SGWT) are well documented in different literatures (e.g., Kahlown and Azam, 2002; Kahlown *et al*., 2005; Dinka, 2010; Matsuo *et al*., 2017).

On the other hand, the shallow groundwater (SGW) in the irrigated area can be a source of water for crops as capillary rise (in situ), or as irrigation water supply (Ayars and Schoneman, 1986). In irrigated areas with SGWT, improvements in irrigation practice are required to avoid excessive irrigation applications and maximize the utilization of the soil moisture coming from SGWT. Water saving practices such as deficit irrigation enhances the contribution of SGWT to evapotranspiration (crop water use) (Awan *et al*., 2012; Florio *et al*., 2014; Xu *et al*. 2016; Gao *et al*., 2017a; Gao *et al*., 2017b; Wang *et al*., 2018; Xue *et al*., 2017), hence increases irrigation water productivity.

A study by Singh (2018) suggested increasing groundwater use and reducing canal water use, and conjunctive use of groundwater with canal water as an alternative management options for irrigation-induced salinization and waterlogging problems. In this case, SGW can be pumped and used in conjunction to surface water for irrigation purpose either by blending or cyclic use as little difference can be observed between them (Chauhan *et al*., 2007). In addition, the use of water-saving irrigation technologies is one central way to promote water conservation in irrigated areas (Peck *et al*., 2004; Nikouei *et al*., 2012). The use of drip and sprinkler irrigation can help reduce the amount of water loss through deep percolation and the rise of shallow groundwater table. The high labour demand and low water use efficiency as the result of deep percolation and tail water loss in commonly used furrow irrigation method, and the increasing demand for scarce water resources has led to greater adoption of overhead or drip irrigation methods for sugarcane production (Narayanamoorthy, 2005; Gunarathna *et al*., 2018). For example, surface and subsurface drip irrigation can save 22.7% to 30.7% of water as relative to surface irrigation (Mahesh *et al*., 2016). Subsurface drip irrigation was promoted for sugarcane production as it would save the irrigation water by about 2860 m^3/ha to 4380 m^3/ha as compared with furrow irrigation system (Silalertruksa and Gheewala, 2018).

Another new alternative for sugarcane crop irrigation is the optimized subsurface irrigation system (OBSIS) which is a solar-powered automatic subsurface irrigation system that creates a phreatic zone below crop roots and relies on capillarity to supply water to the root zone through perforated pipes (Gunarathna *et al*., 2017). This technology provided a higher irrigation water use efficiency compared with sprinkler system under subtropical conditions (Gunarathna *et al*., 2018). The combined use of the precision irrigation techniques and irrigation water management practice such as water canopy-cooling can help tackle the increase water vapour demand due to the extreme high temperature (Iglesias and Garrote, 2015; Houston *et al*., 2018). For example, combining evaporative cooling practice by using a mini sprinkler precision irrigation technique increased water saving by 34% and marketable heads of globe artichoke by 60% (Deligios *et al.*, 2019).

SGWT can contribute from 20% to 40% of the evapotranspiration in arid and semi-arid irrigation districts (Liu *et al*., 2016). However, the amount of contribution of SGWT in meeting the crop water requirements (ETg) varies with its water-table depth (Kahlown and Azam, 2002; Kahlown and Ashraf, 2005). A study by Kahlown and Azam (2002) proved that maximum yield of sugarcane was obtained at groundwater table depth of 2 m or below. Similarly, Kahlown and Ashraf (2005) showed that the optimum water-table depth for all crops studied such as wheat, sugarcane, maize, sorghum, berseem and sunflower was 1.5-2m. About 41% and 6% of the ETg can be contributed from SGWT depths of 1 and 2 meters, respectively (Gao *et al*., 2017b), and up to 50% of the ETg from shallow groundwater depth of less than 1.2 m (Ayars *et al*., 2009). Therefore, the use of shallow groundwater can decrease the need for irrigation water.

The use of shallow groundwater (SGW) can contribute a substantial share to actual evapotranspiration of cotton and alleviate water stress in response to suboptimal amount of water applied for irrigation (Forkutsa *et al*., 2009a) but triggers secondary soil salinization of the topsoil (Forkutsa *et al*., 2009b). The use of high saline SGW (> 4 dS/m) can increase salinity in the soil profile and groundwater, and decrease crop yield through time. Therefore, periodic leaching will be required for in situ use of SGW to be a sustainable practice (Ayars *et al*., 2009). Conjunctive use of surface and shallow groundwater has to be implemented in order to avoid this salinization due to SGW use by practicing proper irrigation scheduling to increase the yield by reducing deep percolation and waterlogging.

Conjunctive use of surface and groundwater consists of harmoniously combining the use of both sources of water in order to minimize the undesirable physical, environmental and economic effects of each solution and to optimize the water demand-supply balance (FAO, 1995). In this case, however, as a certain amount of deep percolation (leaching) is required to control salinity, development of SGW is inevitable. This SGW can be considered as a safety net against unreliable water delivery (Forkutsa *et al*., 2009a). As SGW also recharges deeper aquifers and constantly feeds streams and wetlands, knowledge of its quality is vital for management of these resources. Water quality can have a significant influence on soil properties and their management as well as crop yield. Poor water compositions may cause toxicity, salinity, nutrient deficiency and unavailability, infiltration, and other miscellaneous problems (Ayers and Westcot, 1994). Hence, understanding the quality of any water sources is crucial to make insightful management decisions for sustainable productivity of irrigated land.

Many groundwater quality researches were conducted in different areas of the world (e.g., Harter *et. al*., 2002; Sarkar and Hassan, 2006; Abderrahman *et al*., 2010; Obiefuna and Sheriff, 2011; Reddy, 2013; Masoud, 2014; Bob *et al*.; 2016; Abdel-Satar *et al*., 2017; Aher *et al*., 2017; Dłużewsk *et al*., 2017; Murtadha *et al*., 2017; Selvakumar *et al*. 2017; Ren *et al*., 2018). However, in general studies on conjunctive use of SGW for irrigation purpose are limited and not available for WSSE. The use of SGW for irrigation as an alternative means to tackling waterlogging problem and source of irrigation water supply was not studied. Little information is known about the impact of irrigation on groundwater quality and/or SGW and the possible use of SGWT for irrigation. Knowledge of SGW suitability for irrigation purpose is a prerequisite before its utilization for irrigation.

Therefore, the objective of the study was to examine the suitability of SGW for irrigation purpose and the possibility of its conjunctive use in the future with surface water in WSSE. The study aids the irrigation managers in making appropriate decisions in managing the ever-rising groundwater table and the associated waterlogging, salinization and allied problems resulted from improper irrigation management practices. The study plays a significant role in sustaining long-term sustainable water and land productivity of WSSE.

METHODOLOGY

Study area description

The study was conducted at Wonji-Shoa Sugar Estate (WSSE), Oromiya Region (Ethiopia). WSSE is the first large scale irrigation scheme established in Ethiopia in 1954 by the

Dutch Company called HVA Amsterdam. The irrigation scheme has more than 8000 ha of sugarcane plantation, and the total crushing capacity of the factory is 3,500,000 kg of sugarcane per day. That means the area has been under a continuous irrigation for more than 64 years. Moreover, majority (70%) of the soils under sugarcane plantation are vertisols (black clay soil) which has its own inherent problems.

WSSE is characterized by an altitude of 1540 m+MSL (mean sea level), mean annual rainfall of 704 mm, minimum and maximum temperatures of 15.2 ºC and 27.6 ºC, respectively, and, and the mean pan evaporation of 6.8 mm/day. The irrigation system is surface irrigation by which water is pumped from Awash River to irrigate sugarcane using furrow irrigation method. The excess water from irrigated land is drained by a surface drainage network and safely disposed to the Awash River (Figure 1).

Analysis of water quality

All groundwater table monitoring piezometers and shallow hand-dug wells constructed at critical locations (Figure 1), were selected as water sampling points. A total of 46 water samples were collected with a 1-liter plastic container attached to a long stick near the end of the irrigation season (May 2010). These water samples were transferred to clean 500 ml polyethylene containers and taken to WSSE laboratory for analysis. The location and number of samples collected were graphically shown in Figure 1. A global positioning system (GPS) was used to measure the sampling locations.

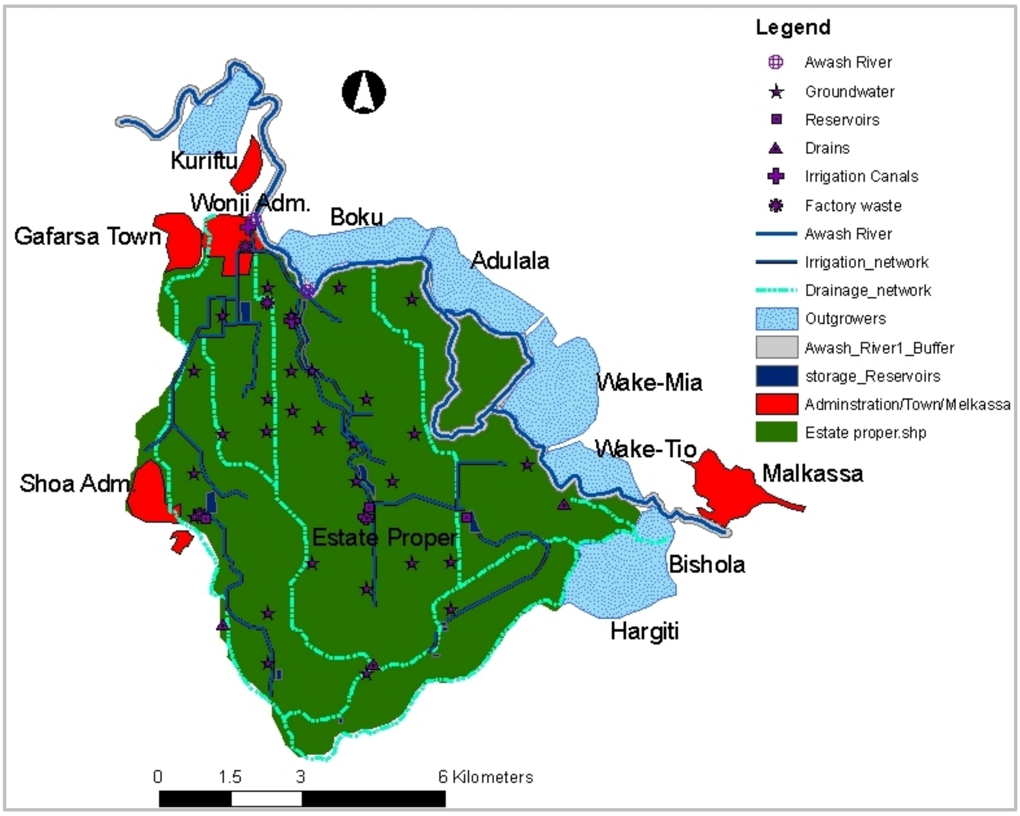

Figure 1. Sampling locations in the study area

Many physicochemical parameters: pH, Electrical Conductivity(EC), Calcium(Ca^{2+}), Magnesium(Mg^{2+}), Sodium(Na^{-}), Potassium(K^{+}), Chloride(Cl^{-}), Carbonate($CO3^{-}$), Bicarbonate(HCO_3), Sulphate (SO_4^{-}), Fluoride (Cl^{-}) and Boron (B^{-}) were determined following standard procedures described in APHA (1995) and Dinka (2015). In addition, water quality indices were calculated using the following Equations (Dinka, 2016).

$$SAR = \frac{Na^{+}}{\sqrt{Ca^{2+} + Mg^{2+}}} \quad (1)$$

$$SSP = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} * 100 \quad (2)$$

$$RSC = (CO_3^{-} + HCO_3^{2+}) - (Ca^{2+} + Mg^{2+}) \quad (3)$$

$$KR = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \quad (4)$$

$$RSBC = HCO_3^{2+} - Ca^{2+} \quad (5)$$

$$PI = \frac{Na^{-} + \sqrt{HCO}_{3}}{Na^{-}Ca^{2+}Mg^{2+}} \quad (6)$$

$$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} * 100 \quad (7)$$

$$TH = (Ca^{2+} + Mg^{2+}) * 50 \quad (8)$$

$$\begin{aligned} TDS &= 640 * EC(forEC < 5dS/m) \\ TDS &= 800 * EC(forEC > 5dS/m) \end{aligned} \quad (9)$$

where, SAR is sodium absorption ratio; SSP is soluble sodium percentage; MAR is magnesium adsorption ratio; RSC is residual sodium carbonate; RSBC is residual sodium bicarbonate; KR is Kelly's ratio, PI is permeability index, MAR is magnesium adsorption ratio; TH is total hardness and TDS is total dissolved solids. The units of all ions are in meq/l (milli equivalent per liter).

Groundwater suitability for irrigation was evaluated according to Ayers and Westcot (1994) guideline. US salinity laboratory diagram (Richards, 1954) was used to evaluate shallow groundwater (SGW) samples with respect to sodicity (SAR) and salinity (EC) hazard. Based on the SAR value, the infiltration problem instead of the permeability was used to describe water quality problem. Finally, SGW quality rating for irrigation use was made based on SAR, EC and RSC values.

RESULTS AND DISCUSSION

Quality composition

The shallow groundwater (SGW) quality composition was shown in Table I. The ranges of the measured values for all parameters (except for Mg^{2+}, CO_3^-, and HCO_3^-) were found within their corresponding usual ranges in irrigation water as stated in Ayers and Westcot (1994). Very few groundwater samples are not within the recommended range for Mg^{2+}, CO_3^-, and HCO_3^-. Moreover, the average value of all parameters including Mg^{2+}, CO_3^-, and HCO_3^- are within the normal range of irrigation water composition. That means the SGW in WSSE is suitable for irrigation. The degree of restriction of the measured values of SGW quality parameters for irrigation purpose was shown under column 5 (Table I). The detail description and associated problems of using the SGWT for irrigation use are stated in the subsequent sub-sections.

Table I. Measured parameters, the usual range in irrigation water (Ayers and Wastcot, 1994) and the degree of restriction on water use for irrigation (University of California Committee of Consultants (UCCC), 1974)

Quality parameter	Unit	Usual range	Measured range	Restriction on use for measured values
EC	dS/m	0–3	0.2-3.0 (1.0) *	None to moderate salinity
TDS	mg/l	0–2000	115–1850 (585)	None to moderate salinity
Ca^{2+}	meq/l**	0–20	1.2–8.0 (2.9)	
Mg^{2+}	meq/l	0–5	0.5–6.2 (1.9)	
Na^{+}	meq/l	0–40	1.4–21.3 (7.5)	
K^{+}	meq/l	0–2	0.0-1.8 (0.3)	
SAR	meq/l	0–15	1.5–12.5 (4.9)	None to severe sodium ion toxicity and infiltration problem
CO_3^{--}	meq/l	0–1	0–1.4 (0.8)	
HCO_3^{--}	meq/l	0–10	3–32 (10.1)	Slight to severe effect on sprinkler irrigated crops
Cl^{-}	meq/l	0–30	0.8–8.5 (1.7)	None to moderate toxicity
SO_4^{--}	meq/l	0–20	0.6–4.3 (1.9)	Normal
pH	1-14	6.5– 8.4	6.9–7.9 (7.5)	Normal
B^{-}	mg/l	0–2	0.2–3.7 (0.5)	None to sever boron ion toxicity
RSC	mg/l	<2.5	1.9–19.5(5.3)	None to severe infiltration problem
MAR	mg/l	<50	27–53 (40)	None to severe infiltration problem
KR	mg/l	<1	0.6–2.3 (1.5)	None to severe infiltration problem
PI	%	>75	75.9-101 (86.6)	Good to moderate permeability

*Values in the bracket are the average of measured water quality parameters;

**meq/l= milli equivalent per liter

Suitability for irrigation

Shallow groundwater (SGW) suitability for irrigation use were discussed below in terms of four irrigation-associated problems: salinity, infiltration rate, specific ion toxicity and scale deposition.

Salinity and sodicity

The electrical conductivity (EC) and total dissolved salts (TDS) are indicative of saline water (Michael, 1992). The EC and TDS values were within the acceptable limits of irrigation water quality for all samples, and the salinity problem would range from 'none to moderate'. Hence, the salinity problem from the use of each SGW would range from 'none to moderate' category. The average salinity of all the SGW falls under slight to moderate category. Therefore, the degree of restriction of the use of all the SGW was slight to moderate.

According to the limits of EC for irrigation given by Bhumbla and Abrol (1972), about 53% of the SGW samples were with very good quality, about 37% were with good quality and about 10% were with marginal (permissible) quality. According to Ayers and Westcot (1994), sugarcane is moderately sensitive crop to salinity with the salinity tolerance level of 1.1 dS/m (Dinka, 2016). Thus, the potential yield expected in the area at the current shallow groundwater (SGW) salinity condition was about 75% to 100%. So the yield reduction of up to 25% and 10% can be expected in 10% of the sample fields (fields 63 (Central) and 201 (South East)) and 30% of the sampled fields (41, 42, 48, 52, 73, 105, 153, 195), respectively if such water is used for irrigation purpose. The average EC of the water was 1.04 dS/m, which is less than the threshold salinity level for sugarcane. Based on this average EC value, 100% of potential sugarcane yield could be produced from the use of SGW for irrigation.

The SAR values of SGW (Table I) were within the usual range in irrigation water (0-15 meq/l). Based on Richards (1954), the SAR was rated excellent for 93% and good for 7% of SGW samples, respectively. The average SAR was 4.9 which was rated excellent for irrigation. Based on EC and SAR, the SGW quality ranges from C_1S_1 (low salinity and low sodium hazard) to C_4S_3 (very high salinity and high sodium hazard). However, based on average values of EC and SAR, SGW of the area was classified under C_3S_1 (high salinity and low sodium hazard) category.

Infiltration problem

Based on the SAR and the EC values of each SGW samples (Table I), the infiltration problem associated with the use of these water samples would range from none to severe. The average infiltration problem would be none to moderate when the average SAR and the EC values are used. Hence, the extreme range of infiltration problem would be reduced from severe to moderate by averaging all SAR and EC of SGW samples.

The infiltration problem was also discussed below using RSC, RSBC, SSP, MAR and KR. The Kelley's Ratio (KR) is between 0.6 and 2.3 with an average value of 1.5. The KR value must not be greater than 1 (Kelley, 1963). But, 90% of the samples have KR > 1.0, which indicate the high proportion of Na^+ over Ca^{2+} and Mg^{2+} (Kelly,1963). This would cause the poor soil tilth/workability with some permeability problem owing to the soil type (vertisol) of the irrigation scheme. The poor soil tilth condition is actually a common problem in the study and frequently reported by the Land Preparation and Clearance Department (LPCD) of the WSSE, which supports the obtained result and the argument stated in Dinka *et al*. (2014).

The range of RSC was from 1.9 - 19.5 with an average value of 5.3 meq/l. A positive value of RSC indicates that the sum of the contents of dissolved ions of Ca and Mg are less than that of CO_3 and HCO_3. Irrigation water is not good as the average RSC of SGW samples was greater than the marginal limit 2.5 (Wilcox, 1958). There is a possibility of infiltration problem with the use of this water. About 60% of the SGW samples did not meet the criteria of safe water (RSC < 5 meg/l) for irrigation purpose (Gupta and Gupta, 1987). This indicates the possibility of infiltration problem from the use of these water sources. Moreover, the water could make the land infertile from the precipitation of $NaCO_3$ (Eaton, 1950). However, the average RSC value was within its marginal range. Conjunctive use SGW and surface water can reduce the infiltration problem.

Magnesium (Mg^{2+}) content of SGW was 0.5 to 6.2 meq/l which was slightly above the normal range (0-5) for few SGW. But the average Mg^{2+} content from all SGW was 1.9 which was within the normal range. The Ca^{++} content of each SGW and their average value was within the normal range for irrigation. In irrigation water, Ca: Mg ratio should be greater than 1 (Ayers and Westcot, 1994; Rahman and Powell, 1979). The lower the Ca/Mg ratio, the more damaging is the SAR (Ayers and Wescot, 1994). The Ca/Mg>1 was satisfied in 90% but not in 10% of the SGW samples. However, the average value of Ca/Mg ratio was 1.5. Conjunctive use of this SGW and surface water would slightly decrease the potential effect of SAR on the soil water infiltration problem. It would also help to decrease calcium-induced nutritional deficiency in plants by improving the Ca/Mg ratio.

The Magnesium Adsorption Ratio (MAR) varied from 27–53, with an average value of 40. Only one sample (3.3%) showed the MAR value exceeding 50, which could cause a harmful effect to the soil (Paliwal, 1972). Other samples (96.7%) have MAR < 50, hence, it causes no harmful effect to the soil. The average MAR value of 40 (which was less than 50) was suitable for irrigation. High magnesium content may affect sugarcane production if the soil is saline (Joshi *et al*., 2009). However, as the magnesium content of the SGW is low it would not affect sugarcane production. Using Doneen's chart (Raghunath, 1987), the values of the permeability index (PI) which ranges from 101% to 75.9% is classified under poor to good soil permeability, respectively. The average of PI was 86.8% (moderate permeability) which is permissible for irrigation but could cause permeability problem in the long run. In general, the average soil infiltration problem that would be associated from the use of SGW ranges from none to moderate, and the soil permeability would be moderate.

Specific –ion toxicity

The specific ion toxicity can complicate the problems of salinity and /or sodicity stated above (Ayers and Wescot, 1994). In this study, the specific ion toxicity problems are discussed in terms of Na^+, Cl^- and B^-.

*Sodium toxicity***.** The sodium ion (Na^+) concentrations of all the samples fall within the recommended values (Table III). However, based on SAR values (Table I), the potential of Na^+ toxicity problems from the use of SGW samples vary from none to severe. From the average values of Na^+, the potential of sodium ion toxicity problem would be slight to moderate. Moreover, as sugarcane is semi-tolerant to sodium toxicity, no significant sodium toxicity problem would be expected. Blending of the SGW and surface water helps create favorable conditions for calcium and magnesium ions to be adsorbed in the soil instead of sodium ion (Ayers and Wescot, 1994). According to Wilcox (1955), the soluble sodium percentage (SSP) ranges from 45.7 (fall under excellent to good category) to 61.9% (doubtful category). The average SSP of 61.9 for all SGW is classified under poor (doubt full) water category for irrigation.

Chloride and Boron toxicity. The chloride (Cl^-) concentration of the SGW samples had none to moderate toxicity to all plants under surface and sprinkler irrigation. However, the average Cl^- concentration from all SGW samples would have none chloride ion toxicity. High concentration of boron (B^-) is toxic to plants. The B^- toxicity of SGW varies from none to severe for different water samples. However, the average of boron from all SGW would have none boron toxicity.

Scale deposition

Bicarbonate (HCO_3^-) contents were found to vary between 3.6 to 31.6 having 10.1 meq/l as an average value which was normal for surface irrigation, but with slight to severe effect on crops irrigated under sprinkler irrigation. The average of HCO_3^- from all water sources also has severe effect on sprinkler irrigated crops. According to the classification by Raghunath (1987), total hardness was moderately hard, hard, and very hard for SGW samples of 23.3%, 56.7%, and 20%, respectively. Scale deposition on plants or soils would occur due to high concentration of less soluble lime ($CaCO_3$). However, this is not a serious problem in surface irrigated schemes like WSSE. Scale deposition due to an insoluble gypsum ($CaSO_4$) salts was less likely to occur as sulfate content is normal for all SGW sources.

General discussion

Shallow groundwater (SGW) can be considered as safety net at the time of water scarcity or unreliable water delivery, hence its use for irrigation helps to avoid crop failure. However, its quality should meet standards for irrigation suitability. Based on water quality evaluation, SGW is suitable for irrigation use. As the EC of SGW is below the threshold salinity level for sugarcane plantation, 100% of potential sugarcane yield could be produced by using SGW for irrigation. Similarly, SAR was also rated excellent for irrigation. Based on average values of EC and SAR, SGW of the area was classified under C_3S_1 (high salinity and low sodium hazard) category. The high salinity of the SGW could be decreased if it is used conjunctively with surface (canal) water. This would help to maintain long term productivity of the irrigation scheme.

From the average values of water quality parameters, infiltration problem was rated moderate, both B^- and Cl^- toxicity was none, the potential of sodium ion toxicity problem was slight to moderate. As sugarcane is semi-tolerant to sodium toxicity, no significant sodium toxicity problem would be expected from the use of SGW. Bicarbonate (HCO_3^-) contents were found to be normal for surface irrigation, but with slight to severe effect on crops irrigated under sprinkler irrigation. Scale deposition on plants or soils would occur due to high concentration of less soluble lime ($CaCO_3$). However, this is not a serious problem in surface irrigated schemes like WSSE. The pH of SGW was within the normal range for most crops. Therefore, the pH of the SGW would have none miscellaneous effect to susceptible crops under irrigation.

In general, the rating of SGW was good to excellent for irrigation in terms of EC (Ayers and Wascot, 1994) and excellent in terms of SAR (Richards, 1954). The category of salinity based on average values of EC and SAR was C3S1 (High salinity and low sodium hazard) which is generally good water for irrigation. Therefore, conjunctive use of SGW and surface water would help to reduce the development of salinity due to the long term use of SGW. The authors of this study suggested the potential pumping sites as shown in Figure 2. The pumping sites are systematically selected based on the waterlogging condition. Further study that quantify the amount of the groundwater storage available for CU is highly recommended. This in turn requires, in addition to the pumping sites suggested, the design of well layout, well number, well depth, etc.

Conjunctive use (CU) of SGW and surface water of WSSE would help to control groundwater table within recommended soil depth for sugarcane production. This helps to minimize waterlogging, soil salinization, leaching of nutrients and fertilizer, creates favourable soil condition for tillage and cultivation. Hence, CU of SGW can help to increase sugarcane productivity. CU also enhances irrigation water productivity by introducing deficit irrigation practice and enhancing shallow groundwater table use in the form of capillary rise to plant root zone for crop evapotranspiration. Therefore, this can be the first management option for CU of SGU in the study area as it does not demand for construction of wells, pumping and additional water delivery canals but adequate soil water sensing instruments.

SGW can be considered as safety net at the time of water scarcity or unreliable water delivery, hence the use of SGW helps to avoid crop failure. The second alternative method of practicing CU is either blending or cyclic use of SGW and surface water as little difference can be observed between them in salinity control as stated by Chauhan et al. (2007). Water saving technologies such as drip and sprinkler optimized subsurface irrigation systems can also be used. However, the use of these technologies may demand high cost of installation and maintenance, high energy for operation, skilled man power, enough equipment's and spare parts availability around the study area as compared to surface irrigation. Hence, the commonly used furrow irrigation with proper irrigation scheduling and management is recommended for CU application in the clayey soils of the study area as the second alternative to the in situ use of SGW in combination with deficit irrigation practice.

As the quality of SGW at WSSE is suitable for irrigation, it can be used as supplementary source of irrigation water. Therefore, SGW can increase water supply to the irrigation scheme. By using this SGW, large areas in WSSE can be irrigated and benefit from sugarcane production can be increased. CU of SGW for irrigation also reduces cost of irrigation water delivery as water is found at the point of use. It also decreases/avoids the need for construction of drainage structures to maintain SGW table at recommended depth below the plant root zone.

CONCLUSIONS

Shallow groundwater (SGW) of Wonji Shoa Sugar Estate (WSSE) was evaluated for irrigation suitability using many water quality parameters and indices. The category of salinity based on average values of EC and SAR was C3S1 (high salinity and low sodium hazard) which is very good for sugarcane production., The infiltration problem would be none to moderate. However, a high value of soluble sodium percentage, residual sodium carbonate, and Kelley's ratio indicate a high possibility of the infiltration problem if the SGW is used for irrigation. Therefore, it is advisable to practice the conjunctive use (CU) of SGW and surface water to avoid or minimize the long-term effect of SGW use on soil infiltration and sugarcane productivity. Moreover, surface water irrigation must be managed efficiently by practicing deficit irrigation and avoiding over irrigation. By doing this, shallow groundwater table use for crop production can be enhanced.

The conjunctive use (CU) of SGW and surface water would help to manage: the ever-increasing problems of water logging, soil salinization, and nutrient leaching at WSSE due to SGWT rise. However, before practicing CU of SGW and surface water, the quality of surface water and soil must be evaluated in the study area. The optimum irrigation scheduling that considers the in situ use of groundwater table must be developed and practiced assisted by soil water sensors. In this case optimum levels of surface water irrigation must be determined to avoid over and under irrigation. If there is a need to pump SGW for irrigation use as the second option, the SGW can be used for CU either by blending or cyclic use with surface water. If blending is required, the proportion of the surface water and SGW irrigation must be identified for sustainable sugarcane productivity. In addition, the following studies were recommended in the future: assessment of SGW potential (amount); design of pumping wells including layout, depth and well number; optimal operation and use of SGW and surface water, and evaluation and use of appropriate water saving irrigation methods and practices.

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